OPTIMIZATION OF THE
HEARST
WATER TREATMENT PLANT
FOR CONTROL OF TRIHALOMETHANES

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Hearst
Water Treatment Plant for Control of Trihalomethanes

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EXECUTIVE SUMMARY

BACKGROUND

The two main objectives of the study are:

1. Improvement of the water treatment plant performance to meet the new Ontario Drinking Water Objectives (ODWO) THMs guideline without compromising disinfection. Secondary quality objectives are to achieve a filter effluent turbidity of 0.1 NTU, and to meet the aluminum operational guideline of 100 µg/L.

2. Sustaining long term performance through skills transfer to plant operating staff and recommendations for plant upgrades where required.

The optimization study was funded by the Ontario Ministry of Environment (MOE), and is a cooperative public/private project between the MOE and RAL Engineering Ltd. By optimizing the performance of their existing facilities, municipalities should be capable of producing water that meets the new THMs objective, and also be capable of improved particle removal and lower aluminum residuals, without requiring costly upgrades.

Trihalomethanes (THMs) are by-products created when the chlorine used in the disinfection process reacts with naturally occurring organics. Trihalomethanes are suspected of increasing the risk of cancer following long term exposure. The Ontario government has lowered the guideline from a maximum acceptable concentration of 350 µg/L, measured as a single occurrence, to a maximum acceptable concentration of 100 µg/L based on a running annual average of four quarterly samples.

The associated treatment parameters of turbidity and aluminum residual were also subject of the optimization effort. The ODWO for turbidity is 1 NTU, but current research now indicates that a filter effluent turbidity of 0.1 NTU is needed to provide protection from cryptosporidium. To reduce potential for disease outbreaks, this study will evaluate the feasibility to obtain a turbidity of 0.1 NTU in the filter effluent. The ODWO for aluminum in drinking water is 100 µg /L

The optimization of the Hearst Water Treatment Plant consisted of evaluating the performance of existing treatment units and making changes to plant operation regarding the disinfection process.

EXISTING CONDITIONS

The Hearst Water Treatment Plant was built in 1977 and treats water from the Mattawishkwia River. The plant is owned by the Town of Hearst and operated by the Ontario Clean Water Agency (OCWA). The Hearst Water Treatment Plant consists of a conventional process including coagulation/flocculation, clarification, filtration and disinfection. The coagulation process is performed with alum, and lime is used for alkalinity adjustment. These chemicals are fed into the raw water main.

In 1996 disinfection was carried out by pre and post-chloramination. Ammonium sulphate was added into the raw water well prior to the addition of chlorine to form chloramines. Both ammonia sulphate and chlorine were fed into the high lift pump suction to 'top up' the level of chloramines. A ground storage reservoir is located at the water treatment plant site. The reservoir is interconnected to the clearwell. The high lift pumps draw the treated water either from the clearwell and/or from the reservoir depending on the demand and the treatment process operation.

A summary of historical data from May 1995 to May 1996 is presented as follows:

Parameters	*Units*	*Raw Water*	*Treated Water*
Turbidity	NTU	2.2 to 7.3	0.2 to 0.2
Colour	TCU	98 to 136	2 to 4
pH		7.0 to 7.6	6.4 to 7.3
Alkalinity	mg/L-$CaCO_3$	36 to 90	23 to 64
THMs-Plant Effluent	µg/L		90 to 285
THMs-Distribution System	µg/L		100 to 271

Plant flows are generally:	Average day	2,200 m^3/d (0.5 MIGD)
	Maximum daily flow	3,700 m^3/d. (0.8MIGD)

PERFORMANCE ASSESSMENT

Water samples were collected at the treatment plant in July and August 1996 to evaluate the performance of the plant versus colour and turbidity removal and THMs formation. The following is a summary of analytical results for that period:

- The average turbidity of the raw water measured at the plant was 5.1 NTU. The average treated water turbidity for July and August was 0.1 NTU, which meets the goal of this study regarding turbidity levels in the filter effluent.

- The raw water colour was high with an average of 92 TCU. The treated water colour remained below the ODWO of 5 TCU with a consistent value of 4 TCU. The levels of total organic carbon (TOC) in the raw water was 13.9 mg/L with an average TOC level in the treated water of 4.6 mg/L showing a 67% removal.

- The THMs levels in the treated water at the treatment plant for July and August 1996 varied from 14 to 91 µg/L with an average of 34 µg/L. The THMs concentration in the distribution system varied from 14 to 22 µg/L with an average of 19 µg/L which is well bellow the ODWO of 100 µg/L.

An evaluation of each process unit including the flocculation tanks, clarifiers, and filter units indicated that all units are being operated well under their rated capacity. The Hearst Water Treatment Plant was designed for an equivalent population of approximately 25,000 people, and the actual population is only 5,960.

At the time of the MOE evaluation of plants (1995) with apparent THMs levels above 100 µg/L, the Hearst plant was practicing pre-chlorination with a free chlorine residual, and post-chloramination directly into the high lift pump suction. Once the issue of the THMs became known the operating authority, OCWA, converted the 'free' pre-chlorination to pre-chloramination by adding ammonium sulfate in the raw water well. With the addition of ammonium before chlorine there was no free chlorine residual formed. The THMs levels fell to very low levels as expected. It was assumed that the presence of a 4,090 m^3 (900,000 IG) reservoir at the plant site would provide the contact time required for inactivation of cysts and viruses by the much slower acting chloramines.

The 4,090 m^3 reservoir is connected to the treatment plant clearwell and high lift pumps with a single pipe. The high lift pump suction is connected to the same pipe that transports water from the clearwell to the reservoir. It would be normal therefore for the high lift pumps to draw water directly from the clearwell alone or in combination with the reservoir depending on the plant production rate and the number of high lift pumps operating. For instance, if only one high lift pump is on but the plant is producing excess water to fill the reservoir, the pumps would be supplied from the clearwell only and the volume in the reservoir would not be available for chlorine contact time.

The requirement for disinfection using chloramines, based on the recommendations by the USEPA and the AWWA are most critical in cold water and when considering viruses. A CT of 1,243 is required for the recommended 2.0 log virus inactivation at 1°C. By comparison when disinfecting with free chlorine, the critical disinfection parameter is cysts. A CT of 46.5 is required to achieve the recommended 0.5 log inactivation at 0.5°C and a pH of 7.5. As indicated, primary disinfection with chloramine would require extremely high chloramine dosages given the available volume and contact time.

CONCLUSIONS

The Hearst Water Treatment Plant experienced levels of THMs exceeding the Ontario Drinking Water Objective of 100 µg/L during the summer months prior to 1996. As a result, addition of ammonium sulphate to the low lift pumps well was initiated in 1996 to perform chloramination of the raw water. This considerably lowered the THMs formation below the new 100 µg/L guidelines.

Information collected from the water plant showed that the total chlorine residual was normally maintained around 1.0 mg/L. At no time in the process was a free residual formed. This may have resulted in inadequate inactivation of viruses and is not a recommended practice.

RECOMMENDATIONS FOR PLANT SCALE MODIFICATIONS

The previous operation was not adequately disinfecting the treated water and there was an increased risk of water borne pathogens. The following actions were recommended:

1. Discontinue the pre-chloramination but retain a chlorine feed connection for periodic 'shock' chlorination of the process tankage if required.
2. Chlorinate to a free residual in the clearwell such that the minimum CT for the inactivation of cysts is met. This should be 0.5 log assuming 2.5 log removal through the filtration process.
3. Construct baffles in the clearwell to reduce the short circuiting.
4. Chloraminate in the discharge from the clearwell to allow a combined residual to be carried through the on-site reservoir.
5. Maintain the existing post-chloramination feed system into the suction of the high lift pumps to 'top up' the combined residual high enough to maintain a combined residual of 1.0 mg/L throughout the distribution system.

CAPITAL WORKS

The capital works required to achieve the above recommendations were implemented by the Town in February 1998. These were:

1. Construction of baffles in the clearwell to reduce short circuiting. The greater the extent of baffling the less the short circuiting and higher the effective contact time. The T_{10}/T factor estimated at 0.1 for the previous arrangement was increased to 0.5 with a relatively simple baffling arrangement.
2. Installation of a chlorine solution feed pipe and diffuser to the clearwell.
3. Installation of an in-line free chlorine residual analyzer on the clearwell discharge for control of the chlorine residual and the free chlorine to ammonium-nitrogen ratio.
4. Installation of an in-line total chlorine analyzer on the high lift discharge.

It is reported the diffuser for the ammonium feed in the pipe between the clearwell and the reservoir was not installed, however this is a critical item for control of the combined residual in the large reservoir.

COST SUMMARY FOR IMPLEMENTATIONS

A summary of capital expenditure for the implementation of the recommended up-grades is presented in the following table:

Capital Costs

CAPITAL ITEMS	COST ($)
Contract for Construction of Baffle Walls	$ 7,052.41
Engineering Design, Supervision, and Work Preparation for Construction of Baffles. Installation of Chlorine Pipe	$ 3,654.27
Advertisement	$ 219.18
Material Purchased for Baffle Walls and Chlorine Pipe	$ 1,454.43
Chlorine Analyzer and Chart Recorder	$ 4,896.53
TOTAL:	**$ 17,276.82**

Fifty percent of the capital cost was assumed by the MOE, and the remaining portion by the Town of Hearst.

It is expected there will be a reduction in total chlorine and ammonium sulphate consumption since the majority of the organics present in the raw water will be removed in the coagulation/clarification/filtration process prior to chlorination. Existing operating data will determine the extent of this saving but a reduction in the order of 25% is expected.

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1.0 BACKGROUND

Trihalomethanes (THMs) are by-products created when the chlorine used in the disinfection process reacts with naturally occurring organics (eg. formed by decay of algae and vegetation) in raw water. Surface water containing high organics also often has high colour levels. The most common forms of trihalomethanes created are chloroform, bromodichloromethane, chlorodibromomethane and bromoform.

The formation of THMs is influenced by several factors:

- Free chlorine concentration - higher Cl_2 = higher THMs
- Organic content - higher organic concentration = higher THMs
- pH - higher pH = higher THMs
- Temperature - higher temperature = higher THMs
- Time - normally longer time = higher THMs

Since the formation of trihalomethanes is associated with the presence of organics in the water, small inland lakes and rivers, which may contain more organics than large clear bodies of water have a greater trihalomethanes formation potential, especially during periods of high runoff.

The reason for adding chlorine to drinking water is to kill bacteria and other microorganisms that could cause numerous illnesses. However chlorine use leads to the presence of trihalomethanes and this is a cause for concern; studies have found an association between high levels of trihalomethanes in chlorinated drinking water, and slight increases in cancer following long term exposure of more than 35 years.

Chlorine has an advantage over other disinfectants in that it persists many hours or for days and provides protection for the entire water distribution system. The benefit to public health of using chlorine as a disinfectant in drinking water far out-weighs the risk to health associated with the low levels of trihalomethanes created as by-products of chlorination. In order to decrease the health risk from trihalomethanes, the Canadian and Ontario governments have lowered their respective guideline limits from an "anytime" maximum acceptable concentration of 350 μg/L, measured as a single occurrence, to an interim maximum acceptable concentration of 100 μg/L based on a running annual average of four quarterly samples.

Disease outbreaks caused by giardia and cryptosporidium have been reported with increased frequency over the last decade in Canada and the US. These protozoan parasites (especially cryptosporidium) are more difficult to kill than bacteria with disinfectants, and therefore their removal by physical processes is vital. As a result, Health Canada is now examining the need for stricter standards for particle removal in water plants. The current Ontario Drinking Water Objective (ODWO) for turbidity that applies at the water treatment plant is 1 NTU, but current US research and experience now indicates that a filter effluent turbidity of 0.1 NTU is needed to provide protection from cryptosporidium. In the attempt to reduce potential for disease outbreaks, this study attempted to evaluate the feasibility to obtain a turbidity of 0.1 NTU in filter effluent.

Alum (aluminum sulphate) is the most widely used coagulant because it is effective, readily available, and relatively inexpensive. However, under some circumstances, or if not used properly, its use can result in elevated levels of residual aluminum in finished drinking water. An article was published on facts about human health and aluminum in drinking water (Environmental Science and Engineering Magazine, January 1997). The following is a summary of the major facts presented in the article.

In recent years, increased attention has been focused on possible adverse effects of aluminum in drinking water on human health. Several epidemiological studies have reported a slightly increased incidence of dementia in communities where drinking water is high in aluminum and these studies have raised concerns among the media and public. A number of theories on the causes of Alzheimer's disease have been proposed and are currently under investigation. From what we know at this time, the evidence linking aluminum and Alzheimer's disease is far from conclusive, but we also cannot be sure that there is no relationship. Humans are constantly being exposed to aluminum via food, air, and water. Ninety percent (90%) of aluminum intake is from food. In general, exposure to aluminum from drinking water is very low (below 3%) compared with that from food and drugs. At the present time the ODWO for aluminum in drinking water is 100 ug/L, which is an operational not health related guideline.

Owners of water treatment plants and water distribution systems who provide water for consumption have legal responsibilities which are shared by all suppliers of food or drink. Owners and suppliers must take reasonable measures to ensure the water is fit for safe consumption.

This optimization study is funded by the Ontario Ministry of Environment (MOE), and is a cooperative public/private project between the MOE and RAL Engineering Ltd. By optimizing the performance of their existing facilities, municipalities with a conventional water treatment plant (i.e. coagulation, flocculation, settling, filtration and disinfection) in many cases should be capable of producing water that meets the new THMs objective, and also be capable of improved particle removal, without resorting to costly upgrades. The optimization of a water treatment plant consists of:

- Documentation of existing facility.
- Assessment of the performance of each process unit.
- Verification of the hydraulic loading on each process.
- Make required changes to plant operation at full-scale to ensure that changes will minimize the formation of THMs, but will not compromise the disinfection requirement.

2.0 OBJECTIVES

The two main objectives of the study are:

1. IMPROVEMENT OF THE HEARST WATER TREATMENT PLANT PERFORMANCE

- Improve plant performance without major capital/equipment expenditures. Specific water quality objectives are listed below in decreasing order of priority:

  i To comply with the 100 µg/L ODWO for THMs in treated water as a running annual average of 4 quarterly samples. This objective shall be met while ensuring proper removal and/or inactivation of disease-causing microorganisms such as bacteria and viruses, since this remains the most critical aspect of drinking water treatment.

  ii To improve particulate removal to reduce or eliminate disease risk from giardia and cryptosporidium. While the ODWO for turbidity is 1.0 NTU, the goal is to achieve 0.1 NTU in the filter effluent.

  iii To keep aluminum residual at or below 100 µg/L to meet the ODWO.

2. SUSTAINING LONG-TERM PERFORMANCE

- Skills transfer to plant operating staff to enable them to effectively control and adjust processes over the long term in response to raw water quality variations.
- Documentation of plant conditions with recommendations for up-grades and operational modifications.

3.0 DOCUMENTATION OF EXISTING CONDITIONS

The water treatment plant was built in 1977. The plant is owned by the Town of Hearst and operated by the Ontario Clean Water Agency (OCWA). There is one superintendent and 2 operators attending to the plant operation 8 hours per day. A plant survey was performed during a site visit on June 18, 1996 to prepare a detailed description of the existing equipment and the condition of operation. The survey is documented in Appendix A. A plant schematic is presented in Figure 3.1.

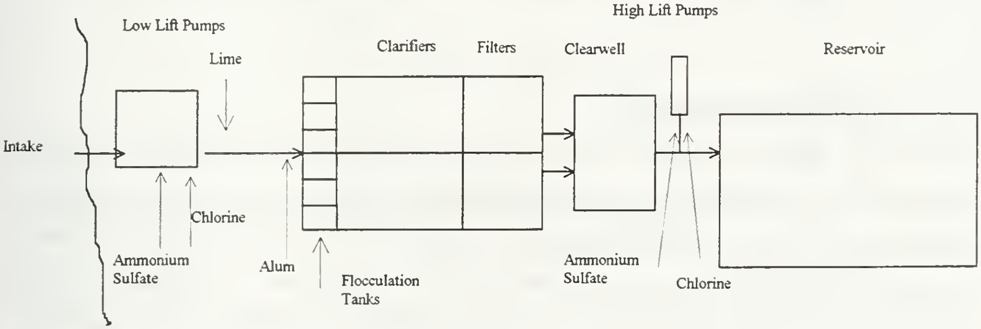


FIGURE 3.1 HEARST WATER TREATMENT PLANT SCHEMATIC IN 1996

The raw water characteristics are:

Colour:	100 to 136 TCU
Turbidity:	2.2 to 7.3 NTU
pH:	7.0 to 7.6
Alkalinity:	36 to 90 mg/L

Plant flows are generally:	Average day	2,200 m^3/d (0.5 MIGD)
	Maximum daily flow	3,700 m^3/d (0.8 MIGD).

At the beginning of the study the water treatment plant consisted of:

- ⇒ Low lift pumping station drawing raw water from the Mattawishkwia River.
- ⇒ Coagulant feed system for alum.
- ⇒ Pre-alkalinity adjustment with lime.
- ⇒ Two settling tanks.
- ⇒ Two dual media filters.
- ⇒ A one-celled clearwell and a ground level storage reservoir.
- ⇒ Chlorine and ammonium sulphate feed systems for pre and post-chloramination.
- ⇒ High lift pumps.

3.1 TREATMENT PROCESS

The Hearst Water Treatment Plant consists of a conventional process including coagulation/flocculation, clarification, filtration and disinfection. The coagulation process is performed with alum and lime is used for alkalinity adjustment. These chemicals are fed into the raw water main. Dosages are flow paced and the process is monitored by an in-line pH meter. In 1996 disinfection was carried out by pre and post-chloramination. Ammonium sulphate was added into the raw water well prior to the addition of chlorine to form chloramines. Both ammonium sulphate and chlorine are fed into the high lift pump suction to 'top up' the level of chloramines. A ground storage reservoir is located at the water treatment plant site. The reservoir is interconnected to the clearwell. The high lift pumps draw the treated water either from the clearwell and/or from the reservoir depending on the demand and the treatment process operation. A copy of the Certificate of Approval is presented in Appendix B.

A process unit model when operated at design flow (11,180 m^3/d) is as follows:

CONVENTIONAL WATER TREATMENT PLANT
(TWO EQUAL UNITS)

MIXING	FLOCCULATORS (2 tanks with 3 cells each)			CLARIFIERS (2 units)			FILTERS (2 units)		
	L	2.9	m/cell	L	15.2	m	L	4.9	m
	W	2.9	m/cell	W	6.0	m	W	4.9	m
	D	6.4	m	D	6.4	m	D		m
NONE	VOL	53.8	m^3	AREA	91.2	m^2	AREA	23.5	m^2
				VOL	583.7	m^3	VOL		m^3
				RATE	2.55	m/h	RATE	9.9	m/h
				TIME	150	min			
	TIME	14	min/cell						

MOE GUIDELINE

		Min.	1.6	m/h	Recom.	9	m/h
		to	2.4	m/h	Max.	12	m/h

A description of the process units operation associated with the plant is:

3.1.1 Low Lift Station

The low lift pumping station includes three (3) submersible pumps, two duty and one standby, each capable of pumping 64.7 L/s (1.23 MIGD) against a total dynamic head of 13.1 m.

3.1.2 Flocculation

There are two (2) sets of spiral flow flocculation tanks each with three (3) cells. The overall dimensions are approximately 2.9 m x 2.9 m x 6.4 m deep per cell. The flocculation tanks are arranged for parallel flow through the two sets with a design flow through each set of 5,590 m^3/d providing a detention time of approximately 42 minutes.

3.1.3 Sedimentation

The plant process includes two (2) settling tanks each 6 m x 15.2 m x 6.4 m deep, arranged for parallel operation to provide approximately 2.5 hours detention time for each tank and a rise rate of 2.6 m/h at the plant rated capacity (11,180 m^3/d). The settling tanks are equipped with syphoning equipment for removal of sludge to a sludge holding tank.

3.1.4 Filtration

Two (2) dual media filters are available at the plant each having overall dimensions of 4.85 m x 4.85 m and a surface area of 23.5 m^2. The filtration rate at plant rated capacity is 9.9 m/h. Each filter is equipped with gravel/sand/anthracite filter media, a surface wash system and wash water troughs. The filtered water discharges to a clearwell below the filters.

One (1) washwater pump having a capacity of 300 L/s (5.7 MIGD) at a total dynamic head of 11.3 m is used for backwashing the filters. The backwash rate is 45 m/h (15 IGPM per square foot).

3.1.5 High Lift Pumps

The high lift pumping station is equipped with four (4) horizontal centrifugal pumps with the following capacities:

- Pump #1: 26 L/s (0.5 MIGD) at 53 m total dynamic head (TDH).
- Pump #2: 53L/s (1 MIGD) at 53 m TDH.
- Pump #3: 106 L/s (2 MIGD) at 53 m TDH with diesel engine drive.
- Pump #4: 80 L/s (1.5 MIGD) at 55 m TDH.

High lift pumps suction are connected to a 450 mm diameter suction header which is connected to a 600 mm diameter pipe between the clearwell and the ground storage reservoir. The high lift pumps discharge to a 400 mm diameter pump discharge header extending from the station to the 300 mm diameter trunk watermain on Edward Street.

3.1.6 Clearwell and Reservoir

A single-celled 409 m^3 clearwell is located below the filters and is interconnected with an un-baffled 4,090 m^3 ground storage reservoir located at the plant site.

3.1.7 Wastewater Disposal

A 273 m^3 surge tank is available at the plant to store backwash water for recycling to the low lift pumping station or pumping to the sludge holding tank by a 6.4 L/s (85 IGPM) horizontal centrifugal wastewater transfer pump.

The 66 m^3 sludge holding tank receives the discharge from the clarifier sludge collectors and from the washwater surge tank. The wastewater is pumped by a 23 L/s (300 IGPM) horizontal centrifugal pump to the sanitary sewer.

3.2 CHEMICAL FEED SYSTEMS

A description of the chemical feed systems as they were at the beginning of the study is summarized as follows:

Process Function	*Chemical*	*Locations Added*
Primary coagulant	Alum	Raw water main
Pre-alkalinity adjustment	Lime	Raw water main
Disinfection	Chlorine	Pre: Raw water well outlet Post: High lift pumps suction
	Ammonium sulphate	Pre: Raw water well Post: High lift pumps suction

3.2.1 Alum

The Hearst Water Treatment Plant is equipped with an alum feed system consisting of two (2) 23 m^3 alum storage tanks, and two (2) positive displacement diaphragm type chemical feed pumps, one duty, one standby, for feeding liquid alum solution to the raw water in the low lift pump discharge. Each pump is capable of a maximum output of 95 L/h.

3.2.2 Lime

The lime feed system consists of a volumetric feeder and mixing tank for preparing the dry chemical into a slurry form for feeding by two (2) positive displacement diaphragm chemical feed pumps, one as standby. Each pump is rated for a maximum capacity of 118 L/h. The lime slurry is added to the raw water main to raise the alkalinity prior to the addition of alum.

3.2.3 Chlorine

The chlorine gas system consists of three (3) V-notch chlorinators, one pre, one post and one as standby to both. The chlorinators capacity is 182 kg/d and each are equipped with 69 kg/d rotameters. The applied dosage for pre-chlorine varies from 1.5 to 2.5 mg/L. The post-chlorine dosage ranges from 1.2 to 2.0 mg/L.

3.2.4 Ammonium Sulphate

Two (2) ammonium sulphate feed systems are used at the plant. Ammonium sulphate was added to the low lift pumping well together with chlorine for chloramination of the raw water. This was initiated in 1996 to lower THMs formation. A second ammonium sulphate feed system is also used for post-chloramination of the treated water at the high lift suction header. The applied dosage of ammonium sulphate for pre and post-chloramination varies from 0.4 to 0.8 mg/L.

3.3 HISTORICAL DATA

A summary of historical data from May 1995 to May 1996 is presented in Table 3.1. This table summarized monthly average values for turbidity, colour, pH, alkalinity, aluminum and THMs found in the raw water and the treated water. The water samples were analyzed by the operating staff at the plant with the exception of THMs. The range and annual average from the data in Table 3.1 are summarized below:

Parameters	*Units*	*Raw Water*	*Treated Water*
Turbidity	NTU	2.2 to 7.3	0.2 to 0.2
Colour	TCU	98 to 136	2 to 4
pH		7.0 to 7.6	6.4 to 7.3
Alkalinity	mg/L-$CaCO_3$	36 to 90	23 to 64
Aluminum	µg/L		13 to 28
THMs-Plant Effluent	µg/L		90 to 285
THMs-Distribution System	µg/L		100 to 271

The variation of turbidity in the raw and the treated water from May 1995 to May 1996 is presented in Figure 3.2. The turbidity of the raw water was variable and reached peak values in May and August. The turbidity of the treated water was constant through the year with an average value of 0.2 NTU.

The variation of colour in the raw and the treated water for Hearst Water Treatment Plant is presented in Figure 3.3. The river supply to the plant was high in colour (98 to 136 TCU) and reached its maximum value in November 1995. The treated water colour was relatively constant through the year with an average of 3 TCU. In general the plant is well run with turbidity and colour well within the MOE guidelines indicating good control of the process which gives confidence in the day to day performance.

The average pH of the raw water was 7.3. The pH of the treated water in 1995 and 1996 was generally low and varied between 6.4 to 7.3. The aluminum residual in the treated water varied from 13 to 28 μg/L which is well bellow the Ontario Drinking Water Objective (ODWO) of 100 μg/L.

The THMs levels found at the treatment plant and in the distribution system in August 1995 were high (285 μg/L and 271 μg/L respectively), indicating high THMs formation during the summer months. Levels of THMs from December to March 1995 were just below the ODWO guideline of 100 μg/L, but the annual average for 1995 remained above 100 μg/L. At that time, the disinfection process consisted of performing post-chloramination of the treated water to reduce the THMs formation, and pre-chlorination of the raw water with free chlorine.

TABLE 3.1 HEARST WATER TREATMENT PLANT
MONTHLY AVERAGE WATER QUALITY RESULTS - 1995 AND 1996
WATER SAMPLES ANALYZED BY THE WTP STAFF (EXCEPT FOR THMs)

	May-95	Aug-95	Nov-95	Dec-95	Feb-96	May-96	MINIMUM	MAXIMUM	AVERAGE
TURBIDITY - RAW WATER (NTU)	6.1	6.6	2.2	-	3.7	7.3	2.2	7.3	5.2
TURBIDITY - TREATED WATER (NTU)	0.2	0.2	0.2	-	0.2	0.2	0.2	0.2	0.2
COLOUR - RAW WATER (TCU)	100	127	136	-	98	100	98	136	112
COLOUR - TREATED WATER (TCU)	2	4	4	-	3	3	2	4	3
pH - RAW WATER	7.4	7.6	7.0	-	7.1	-	7.0	7.6	7.3
pH - TREATED WATER	7.3	6.7	6.5	-	6.6	6.4	6.4	7.3	6.7
ALKALINITY - RAW WATER (mg/L-$CaCO_3$)	37	61	37	-	90	36	36	90	52
ALKALINITY - TREA. WATER (mg/L-$CaCO_3$)	34	36	23	-	64	30	23	64	37
ALUMINUM - TREATED WATER (ug/L)	17	24	28	-	16	13	13	28	20
THMs - TREATED WATER (ug/L)	-	285	-	90	-	-	90	285	188
THMs - DISTRIBUTION SYSTEM (ug/L)	-	271	-	100	-	-	100	271	186

NOTES:

THMs RESULTS FOR TREATED WATER IN FEBRUARY 1995 WAS 69 ug/L.

THMs RESULTS FOR TREATED WATER IN MARCH 1995 WAS 53 ug/L.

FIGURE 3.2 TURBIDITY FOR HEARST WTP (1995-1996)

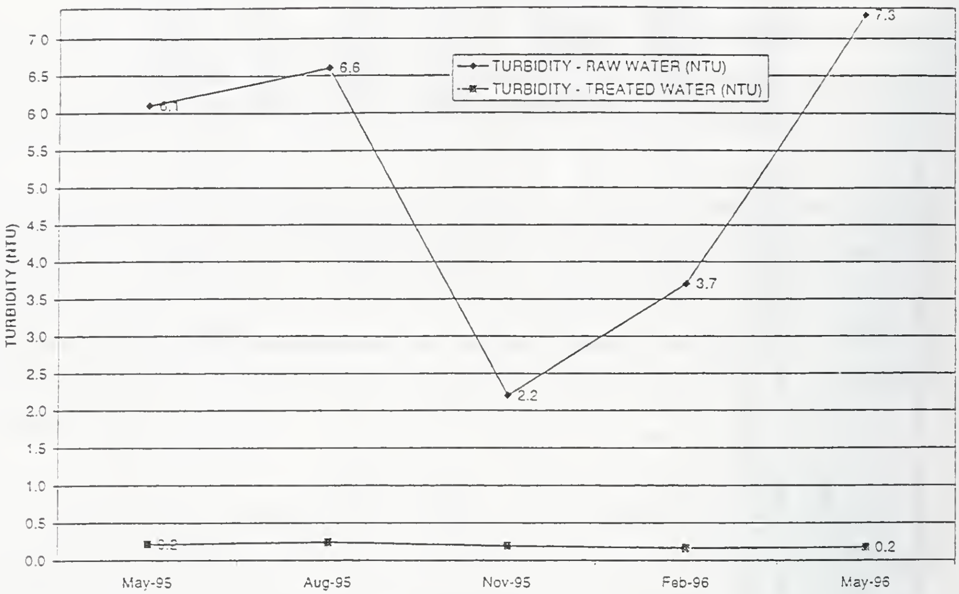
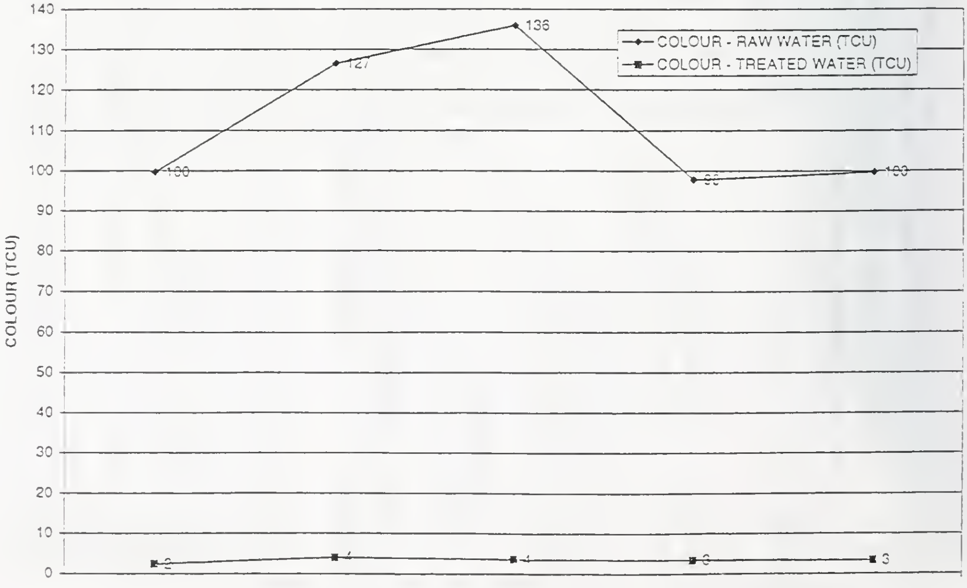


FIGURE 3.3 COLOUR FOR HEARST WTP (1995-1996)



4.0 PERFORMANCE ASSESSMENT

4.1 JULY AND AUGUST 1996 SAMPLING

Additional water samples were collected at the treatment plant in July and August 1996 to establish a baseline for THMs versus the level of colour and Total Organic Carbon (TOC). The samples were analyzed by Novamann laboratories currently operating under Maxxam Analytics. The results obtained from 5 weeks of sampling are summarized in Table 4.1. The operation data collected at the water treatment plant for the days of sampling including average daily flow, turbidity, raw water temperature and chemical dosages are presented in Table 4.2.

The average turbidity of the raw water measured at the plant (Table 4.2) was 5.1 NTU. The average treated water turbidity for July and August was 0.1 NTU which meets the goal of this study regarding turbidity levels in the filter effluent. Turbidity analysis performed at the plant are more accurate than analysis performed at an external laboratory since delay generated by transportation time can modify the property of the water.

The raw water colour was high with an average of 92 TCU. The treated water colour remained below the ODWO of 5 TCU with a consistent value of 4 TCU. The levels of total organic carbon (TOC) in the raw water was 13.9 mg/L with an average TOC level in the treated water of 4.6 mg/L showing a 67% removal.

The THMs levels in the treated water at the treatment plant for July and August of 1996 varied from 14 to 91 μg/L with an average of 34 μg/L. The THMs concentration in the distribution system varied from 14 to 22 μg/L with an average of 19 μg/L which is well bellow the ODWO of 100 μg/L. Plant staff switched from disinfection of the raw water with free chlorine to pre-chloramination to lower the THMs levels when they were made aware of the problem related to high THMs formation during the summer.

TABLE 4.1 JULY AND AUGUST 1996 SAMPLING FOR HEARST WATER TREATMENT PLANT
WATER SAMPLES ANALYZED BY NOVAMANN

PARAMETERS	WEEK 1 (17/07/96)	WEEK 2 (24/07/96)	WEEK 3 (31/07/96)	WEEK 4 (11/09/96)	WEEK 5 (18/09/96)	MINIMUM	MAXIMUM	AVERAGE
Turbidity - Raw Water (NTU)	4.8	3.4	4.9	5.5	5.4	3.4	5.5	4.8
Turbidity - Treated Water (NTU)	0.2	0.2	0.2	0.9	0.7	0.2	0.9	0.4
Colour - Raw Water (TCU)	101	105	96	77	81	77	105	92
Colour - Treated Water (TCU)	4	4	4	4	4	4	4	4
Colour - Distribution System (TCU)	6	6	6	6	5	5	6	6
pH - Raw Water	7.8	7.4	7.4	8.0	8.2	7.4	8.2	7.8
pH - Treated Water	7.4	7.1	6.9	7.6	7.6	6.9	7.6	7.3
Alkalinity - Raw Water (mg/L - $CaCO_3$)	35	35	45	69	69	35	69	51
Alkalinity - Treated Water (mg/L - $CaCO_3$)	22	22	25	40	47	22	47	31
TOC - Raw Water (mg/L)	11.5	14.5	13	15.4	15.1	11.5	15.4	13.9
TOC - Treated Water (mg/L)	3.3	4.4	4.1	5.6	5.6	3.3	5.6	4.6
TOC - Distribution System (mg/L)	4.8	4.2	4.8	5.8	5.1	4.2	5.8	4.9
THMs - Unquenched Treated Water (ug/L)	91	23	21	21	14	14	91	34
THMs - Quenched Distribution System (ug/L)	14	17	20	22	22	14	22	19

TAABLE 4.2 JULY AND AUGUST 1996 SAMPLING FOR HEARST WATER TREATMENT PLANT
OPERATION DATA COLLECTED AT THE WTP

PARAMETERS	WEEK 1 (17/07/96)	WEEK 2 (24/07/96)	WEEK 3 (31/07/96)	WEEK 4 (11/09/96)	WEEK 5 (18/09/96)	MINIMUM	MAXIMUM	AVERAGE
Average Daily Flow (m^3/d)	1,980	2,356	2,619	3,431	2,771	1,980	3,431	2,631
Turbidity - Raw Water (NTU)	4.0	4.1	4.8	6.0	6.6	4.0	6.6	5.1
Turbidity - Treated Water (NTU)	0.1	0.1	0.1	0.2	0.1	0.1	0.2	0.1
Temperature - Raw Water (Degree Celsius)	18.0	18.5	18.5	15.5	12.0	12.0	18.5	16.5
Free Chlorine Residual (mg/L)	0.07	0.06	0.04	0.06	0.03	0.03	0.07	0.05
Total Chlorine Residual (mg/L)	0.74	0.96	0.94	1.00	0.85	0.74	1.00	0.90
Alum Dosage (mg/L)	215	237	213	175	174	174	237	203
Lime Dosage (mg/L)	59	63	66	51	57	51	66	59
Ammonium Sulphate Dosage - Pre-Disin. (mg/L)	1.5	1.6	1.1	0.7	0.8	0.7	1.6	1.1
Pre-chlorine Dosage (mg/L)	N/A	0.3	2.9	1.9	2.0	0.3	2.9	1.8

N/A: Not Available

The water samples taken in the distribution system for THMs analysis were quenched with sodium thiosulfate to remove any chlorine residual to stop any further reaction between free chlorine and organics. Quenched water samples will maintain the same level of THMs as existed at the time of sampling representing the quality experienced by the consumer. The water samples taken at the water treatment plant for THMs analysis were not quenched, the reason being to simulate the effect of additional contact time in the distribution system versus the development of THMs.

Based on THMs, colour and TOC analysis performed for Hearst Water Treatment Plant, there is no evidence of a direct relation between the level of colour or TOC in the water and the level of THMs formed. The lack of THM-colour correlation is somewhat unexpected since in general the higher the colour, the higher the organic content, therefore producing higher THMs. In addition to the limited number of samples collected, other factors, which may have contributed to the lack of correlation include, the practice of pre-chloramination, the narrow range of colour value observed, and the analytical variability for THMs analysis. The detection limit of the analytical procedures and the method reference used by Novamann is summarized in Appendix C.

4.2 PROCESS UNIT ASSESSMENT

4.2.1 Flocculation

The two flocculation tanks were designed for a total mixing and contact time of 42 minutes per tank at plant rated capacity of 11,180 m^3/d. The contact time is currently 85 minutes per tank when one low lift pump is operated at its maximum capacity (5,500 m^3/d), which is higher than the maximum daily flow (3,700 m^3/d). The most critical parameter for flocculation of colour is to have adequate time for the particles to agglomerate especially in cold water conditions. The Hearst plant has sufficient residence time in the flocculators.

4.2.2 Sedimentation

The rise rate in the clarifier when one low lift pump is operated at its maximum capacity (5,500 m^3/d) is 1.25 m/h which is below the MOE guidelines (1.6 m/h to 2.4 m/h) (MOE, 1982). At the plant rated capacity the rise rate would be 2.5 m/h which is slightly over the MOE guideline. The Hearst Water Treatment Plant was designed for an equivalent population of approximately 25,000 people. The actual population is only 5,960 people. The large treatment units contribute to the production of high quality water.

4.2.3 Filtration

The filtration rate for a low lift pump rate of 5,500 m^3/d is 4.9 m/h. This is well below the MOE guidelines (9 to 12 m/h) and contributes to the excellent turbidity removal. At the plant rated capacity the filter rate would be 9.9 m/h which is at the low end of the MOE guideline range.

4.2.4 Disinfection

Disinfection of drinking water is the most important aspect of the treatment process. Harmful organisms in water such as bacteria, viruses or cysts can cause illness ranging from minor intestinal disorders to potentially fatal infections. Maintaining an effective disinfection system must be the overriding priority of the plant operations. For surface waters, chlorination with a 'free' residual is the most common and most practical method of disinfection. To be effective, the treated water must be very low in turbidity as suspended particles can shield bacteria and virus from the effect of chlorine. Turbidity levels greater than 0.1 NTU indicate an increased probability of chlorine resistant cysts being present.

To achieve a safe level of disinfection, it is necessary to dose the treated water with a sufficient amount of chlorine to produce a 'free' residual, and to give the chlorine sufficient time to inactivate the potentially harmful organisms. This is called the concentration-time factor or CT, also referred to as the primary disinfection stage. Sufficient CT must be achieved at the treatment plant before the first service connection.

Current MOE guidelines call for a minimum residual of 0.5 mg/L for a minimum contact time of 30 minutes after filtration. This disinfection guideline for water treatment plants in Ontario is under review, and the new guideline may be similar to the Surface Water Treatment Rule (SWTR) promulgated by U.S. Environmental Protection Agency (U.S. EPA). The SWTR established CT values for chlorine, chlorine dioxide, ozone and chloramines required to achieve adequate inactivation of giardia cysts and viruses. For the purpose of calculating CT value, T is the time (in minutes) it takes the water, during peak plant flows, to move between the point of disinfectant application and a point where, C, residual disinfectant (in mg/L) concentration is measured just prior to the first customer. The calculation must take into account the degree of short circuiting in the storage tank.

For free residual chlorination, the CT required is based on the inactivation of giardia cysts in cold water. Giardia cysts are harder to inactivate by free chlorine than viruses, therefore, it is implied that proper inactivation of giardia cysts will ensure inactivation of viruses. Disinfection is not effective for the inactivation of cryptosporidium therefore, it is necessary to perform adequate filtration at the water treatment plant for any municipality at risk of cryptosporidium outbreaks.

Secondary disinfection refers to the maintenance of a residual in the distribution system to protect against bacterial re-growth or minor cross connection contamination. This maintenance residual is commonly achieved with 'free' chlorine, but alternatively can be converted to chloramine or 'combined' residual with the addition of ammonia. Chloramines have the advantage of being more stable and lasting much longer in the system. They also do not react with organics to form THMs. They are however much less effective as a disinfectant and are very weak in inactivating viruses and cysts. Use of chloramine as a primary disinfectant is therefore not recommended.

The MOE guidelines recommend a chlorine residual should be maintained in all parts of the distribution system. The AWWA recommends a residual of 1.0 mg/L of chloramine be maintained to prevent bacterial re-growth (AWWA, 1993).

Based on the "Guidance Manual for Compliance With the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Source" (U.S. EPA, 1990), the baffle condition in the clearwell expressed as T_{10}/T factor can be evaluated to estimate the effective contact time in the clearwell. This factor represents the ratio between T_{10}, which is the time it takes 10 percent of a dye or tracer to pass through the basin outlet after it is injected into the basin influent flow, and the theoretical detention time for plug flow in pipelines and flow in a completely mix chamber.

At the time of the MOE evaluation of plants with apparent THMs levels above 100 μg/L, the Hearst plant was practicing pre-chlorination with a free chlorine residual, and post-chloramination directly into the high lift pump suction. Once the issue of the THMs became known the operating authority, OCWA, converted the 'free' pre-chlorination to pre-chloramination by adding ammonium sulfate in the raw water well. With the addition of ammonium before chlorine there was no free chlorine residual formed. The THMs levels fell to very low levels as expected. It was assumed that the presence of a 4,090 m^3 (900,000 IG) reservoir at the plant site would provide the contact time required by the much slower acting chloramines.

A detailed evaluation of the disinfection was made and compared to both the existing MOE guidelines and the USEPA/AWWA recommendations for the inactivation of cysts and viruses. During the course of this investigation several issues came to light:

1. When tracer studies are not available, a description of the clearwell and baffling condition can be used to estimate the T_{10}/T factor. The clearwell has a maximum volume of 409 m^3 (90,000 IG). However, the filter discharge point and the reservoir/high lift feed pipe are close together and there is no baffling. It is expected the short circuiting factor (T_{10}/T) is 0.1 or less. When combined with an assumption on the normal low water level of 50%, there is less than 8 minutes of actual contact time available in the clearwell at existing maximum day flows, prior to discharge to the community.

2. The 4,090 m^3 reservoir is connected to the treatment plant clearwell and high lift pumps with a single pipe (Refer to Figure 3.1). The high lift pump suction is connected to the same pipe that transports water from the clearwell to the reservoir. It would be normal therefore for the high lift pumps to draw water directly from the clearwell alone or in combination with the reservoir depending on the plant production rate and the number of high lift pumps operating. For instance, if only one high lift pump is on, but the plant is producing excess water to fill the reservoir, the pumps would be supplied from the clearwell only and the volume in the reservoir is not being used for chlorine contact.

3. The requirement for disinfection using chloramines, based on the recommendations by the USEPA and the AWWA are most critical in cold water and when considering viruses. A CT of 1,243 is required for the recommended 2.0 log virus inactivation at 1°C. By comparison when disinfecting with free chlorine, the critical disinfection parameter is cysts. A CT of 46.5 is required to achieve the recommended 0.5 log inactivation at 0.5°C and a pH of 7.5. As indicated, primary disinfection with chloramine would require extremely high chloramine dosages given the available volume and contact time. When adding ammonia before chlorine the USEPA recommend special investigations be carried out on the effectiveness of the disinfection for inactivation of viruses.

4. The current MOE guidelines do not recognize the disinfection achieved prior to filtration due to the shielding effect of particles in the water. The USEPA does give credit for disinfection of unfiltered water however the CT values required to achieve the desired inactivation are so high that, with chloramines, a plant would need several days of residence time.

It was therefore recommended to stop pre-chloramination of the raw water, and to perform disinfection of the treated water in the clearwell with free chlorine. This involves the installation of a post-chlorine injection system with diffuser into the clearwell, and the installation of new baffles to provide the contact time required to achieve the inactivation of giardia cysts with free chlorine. A new injection point for ammonium sulphate should be installed between the pipe connecting the clearwell and the high lift pumps suction for post-chloramination of the water leaving the clearwell. The existing ammonium/chloride feed at the high lift would be maintained to "top-up" the combined chlorine residual to the required level.

The evaluation of minimum residual chlorine concentration required for inactivation of giardia cysts for various raw water temperatures is presented in Appendix D. The results are summarized in Table 4.3. A baffling factor T_{10}/T of 0.5 was used for the calculations representing the new short circuiting condition in the clearwell after installation of baffles. The pH of the raw water used for the calculations was 7.5. This parameter remains relatively constant through the year. The CT calculations were done under the most critical condition when the clearwell is half full and one low lift pump is operated at actual rated capacity (5,500 m^3/d). The contact time in the clearwell is estimated to be 27 minutes for these conditions.

TABLE 4.3 Calculation of minimum residual chlorine concentration required for inactivation of giardia cysts at actual pump flowrate (5,500 m^3/d)

CONDITIONS	**Free Residual Chlorine Concentration (mg/L) C**
• Temperature of the raw water: 0.5 °C	1.74
• Temperature of the raw water: 5 °C	1.14
• Temperature of the raw water: 10 °C	0.82
• Temperature of the raw water: 15 °C	0.52
• Temperature of the raw water: 20 °C	0.37

The results presented in Table 4.3 summarize the minimum free chlorine residual requirement to be maintained in the clearwell at different times of the year for proper inactivation of giardia cysts. The results show that a higher chlorine residual is required during the winter since lower water temperature reduces the rate of inactivation.

In addition to the disinfection requirement, there is a need to ensure sufficient combined residual to protect the distribution system and storage tanks against re-growth or external contamination. If the chlorine residual declines in the distribution system the presence of free ammonia could lead to nitrification. This would result in the development of biological growth that is very difficult to remove once established.

Therefore, a higher free chlorine residual than the minimum concentrations recommended in Table 4.3 should be maintained. A free chlorine residual of 2 mg/L leaving the clearwell should be maintained before combining it with ammonium sulphate to maintain a combined chlorine residual of approximately 2 mg/L leaving the clearwell.

Studies in the United States have indicated that municipalities that maintain a residual of 2.0 mg/L of combined chlorine do not experience nitrification. Where residuals are less than 2.0 mg/L there is a greater risk of nitrification. The amount of risk depends heavily on the chlorine to ammonia ratio and the water temperature. The lower the ratio of Cl_2 to NH_3-N the more excess ammonia there will be and hence more nutrient for the nitrifying bacteria. Also the higher the water temperature the greater the growth rate of the bacteria.

Additional CT calculations were performed to verify the required level of chlorine residual leaving the clearwell for different water temperatures when the plant is operated at design capacity (11,180 m^3/d). The results are presented in Appendix D (D.6 to D.10), and summarized in Table 4.4. The highest water demand occurs during the summer months which is the time of the year when the design flow would be reached. A corresponding flow decrease for the rest of the year based on the same flow proportion presented in Table 4.3 for maximum day flow was used to estimate flow rates for different water temperatures.

TABLE 4.4 Calculation of minimum residual chlorine concentration required for inactivation of giardia cysts at plant rated capacity

CONDITIONS	**Free Residual Chlorine Concentration (mg/L)** **C**	**Contact Time (minutes)** **T**
• Temperature of the raw water: 0.5 °C • Projected flow: 6,100 m^3/d	1.99	24
• Temperature of the raw water: 5 °C • Projected flow: 6,345 m^3/d	1.34	23
• Temperature of the raw water: 10 °C • Projected flow: 7,252 m^3/d	1.11	20
• Temperature of the raw water: 15 °C • Projected flow: 9,065 m^3/d	0.92	16
• Temperature of the raw water: 20 °C • Design flow: 11,180 m^3/d	0.84	13

The results presented in Table 4.4 indicate that the expected plant maximum day flow during the winter would be 6,100 m^3/d when the water temperature is the coldest. The required free chlorine residual in the winter to obtain the minimum recommended CT is 1.99 mg/L. This would be an acceptable concentration when subsequently combined with ammonia to form chloramine.

5.0 CONCLUSIONS

The Hearst Water Treatment Plant experienced levels of THMs exceeding the Ontario Drinking Water Objective of 100 µg/L during the summer months prior to 1996. As a result, addition of ammonium sulphate to the low lift pump well was initiated in 1996 to perform chloramination of the raw water. This considerably lowered the THMs formation below the new 100 µg/L guideline.

Information collected from the water plant showed that the total chlorine residual was normally maintained around 1.0 mg/L. At no time in the process was a free residual formed. This may have resulted in inadequate inactivation of viruses and is not a recommended practice.

During the summer of 1996, water sampling indicated that the turbidity of the treated water ranged from 0.1 to 0.2 NTU with an average of 0.1 NTU, which essentially meets the objective of the present study regarding particle removals. The current ODWO for turbidity is 1 NTU but US research and experience now indicate that a turbidity of 0.1 NTU in the filter effluent is needed to provide protection from cryptosporidium. Disease outbreaks caused by giardia and cryptosporidium have been reported with increased frequency over the last decade in Canada and the US. These protozoan parasites (especially cryptosporidium) are more difficult to kill with disinfectants, and therefore their removal by physical processes is vital. As a result, Health Canada is now examining the need for stricter standards for particle removal in water plants.

The treated water colour remained below the ODWO of 5 TCU with a consistent level of 4 TCU. The aluminum residual in the treated water varied from 13 to 28 µg/L which is well below the Ontario Drinking Water Objective (ODWO) of 100 µg/L. The pH of the treated water in 1995 and 1996 was generally low and varied between 6.4 to 7.3.

6.0 RECOMMENDATIONS

The previous operation was not adequately disinfecting the treated water and there was an increased risk of water borne pathogens. A schematic showing the proposed recommendation to correct this situation is presented in Figure 6.1. The following actions were recommended:

1. Discontinue the pre-chloramination but retain a chlorine feed connection for periodic 'shock' chlorination of the process tankage if required.
2. Chlorinate to a free residual in the clearwell such that the minimum CT for the inactivation of cysts is met. This should be 0.5 log assuming 2.5 log removal through the filtration process.
3. Construct baffles in the clearwell to reduce the short circuiting.
4. Chloraminate in the discharge from the clearwell to allow a combined residual to be carried through the large on-site reservoir.
5. Maintain the existing post-chloramination feed system into the suction of the high lift pumps to 'top up' the combined residual high enough to maintain a combined residual of 1.0 mg/L throughout the distribution system.

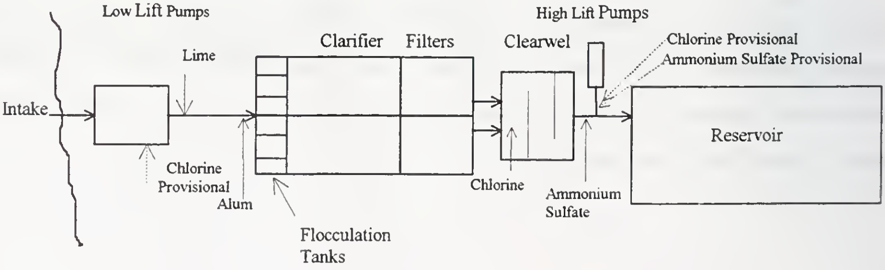


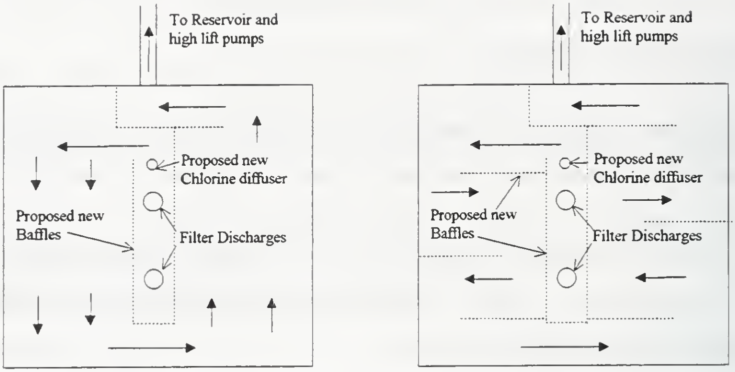
FIGURE 6.1 PROPOSED DISINFECTION PROCESS

6.1 CAPITAL WORKS

The capital works required to achieve the above recommendations were implemented by the Town in February 1998. These were:

1. Construction of baffles in the clearwell to reduce short circuiting. The greater the extent of baffling the less the short circuiting and higher the effective contact time. The T_{10}/T factor estimated at 0.1 for the existing arrangement was increased to 0.5 with a relatively simple baffling arrangement. Estimates of the T_{10}/T factors are taken from the USEPA manual on disinfection (USEPA, 1990). Two proposed baffling concepts are presented in Figure 6.2 ($T_{10}/T=0.5$ and $T_{10}/T=0.7$).
2. Installation of a chlorine solution feed pipe and diffuser to the clearwell.
3. Installation of an in-line free chlorine residual analyzer on the clearwell discharge for control of the chlorine residual and the free chlorine to ammonium-nitrogen ratio.
4. Installation of an in-line total chlorine analyzer on the high lift.

It is reported the diffuser for the ammonium feed in the pipe between the clearwell and the reservoir was not installed, however this is a critical item control of the residual in the large reservoir.


To Reservoir and high lift pumps
Proposed new Chlorine diffuser
Proposed new Baffles
Filter Discharges
To Reservoir and high lift pumps
Proposed new Chlorine diffuser
Proposed new Baffles
Filter Discharges

ESTIMATED T_{10}/T = 0.5 **ESTIMATED T_{10}/T = 0.7**

FIGURE 6.2 PROPOSED CLEARWELL BAFFLING

The baffles installed at the plant in February 1998 are described with a baffling factor $T_{10}/T=0.5$. The arrangement includes baffle walls around the filter effluent discharge and new diffuser, and baffle walls around the clearwell outlet.

7.0 COST SUMMARY FOR IMPLEMENTATIONS

The items that were implemented by the Town during the course of the optimization project are the following:

1. Addition of a new chlorine injection line into the clearwell diffuser and baffles.
2. A chlorine analyzer and chart recorder was purchased and installed.

7.1 CAPITAL COSTS

A summary of capital expenditure involved for the implementation of the recommended up-grades is as follows:

CAPITAL ITEMS	ACTUAL COST
1. Contract for Construction of Baffle Walls (refer to Figure 6.2, $T_{10}/T=0.5$ for layout)	$ 7,052.41
2. Engineering Design, Supervision, and Work Preparation for Construction of Baffles. Installation of Chlorine Pipe	$ 3,654.27
3. Advertisement	$ 219.18
4. Material Purchased for Baffle Walls and Chlorine Pipe	$ 1,454.43
5. Chlorine Analyzers and Chart Recorder	$4,896.53
TOTAL	**$ 17,276.82**

Fifty percent of the capital cost was assumed by the MOE, and the remaining portion by the Town of Hearst.

7.2 OPERATING COSTS

It is expected there will be a reduction in total chlorine and ammonium sulphate consumption since the majority of the organics present in the raw water will be removed in the coagulation/clarification/filtration process prior to chlorination. Existing operating data will determine the extent of this saving but a reduction in the order of 25% is expected.

GLOSSARY AND LIST OF ABBREVIATIONS

Alum	: aluminum sulphate
CT	: Value required to achieve adequate inactivation and/or removal of cysts and viruses. T is the time (in minutes) it takes the water during peak hourly flow, to move between the point of disinfectant and a point where C, the residual disinfectant concentration (mg/L), is measured prior to the first customer.
d	: day
°C	: degree Celsius
DWSP	: Drinking Water Surveillance Program
ECR reagent	: Eriochrome Cyanine R
FID	: Flame Ionization Detector
ft	: foot
G	: flocculation energy gradient
Gt	: flocculation energy
GC/MS	: Gas Chromatograph / Mass Spectrometry
GAC	: Granular Activated Carbon
g	: gram
h	: hour
HFS	: hydroxylated ferric sulphate (Ferriclear)
ICP	: Inductively Coupled Plasma Atomic Emission Spectoscopy
IG	: imperial gallon
kW	: kilowatt
L	: litre
L/cap.d	: litres per capita per day
L/s	: litres per second
m	: metre
m^2	: square metres
m^3	: cubic metres

m^3/d : cubic metres per day

m/h : metres per hour (equivalent $m^3/m^2.h$ - filtration rate)

μg/L : micrograms per litre

mg/L : milligrams per litre

mm : millimetre

mL/min : millilitres per minute

min : minute

NTU : Nephelometric Turbidity Unit

OCWA : Ontario Clean Water Agency

ODWO : Ontario Drinking Water Objective

% : percent

PACL : polyaluminum chloride

PVC : polyvinyl chloride

lb : pound

rpm : revolution per minute

SOR : Surface Overflow Rate

SWTR : Surface Water Treatment Rule

T_{10}/T : This factor describes the baffling condition in the clearwell, and represents the ratio between T_{10}, which is the time it takes 10 percent of a dye or tracer to be detected at the basin outlet after it is injected into the basin influent flow, and the theoretical detention time for plug flow in pipelines and flow in a completely mixed chamber.

TOC : Total Organic Carbon

THMs : Trihalomethanes

TCU : True Colour Unit

W/V : weight/volume

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Environmental Science and Engineering Magazine. Drinking water Update - The Facts About Human Health and Aluminum in Drinking Water, January, 1997.

U.S. Environmental Protection Agency, Science and Technology Branch Criteria and Standards Division of Drinking Water. Guidance Manual for Compliance With the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources, October , 1990.

Ontario Ministry of the Environment, Environmental Approvals and Land Use Planning Branch. Guidelines for the Design of Water Treatment Works, April 1982.

APPENDICES

Plant Survey

Appendix A

PLANT **Hearst Water Treatment Plant**
Shipping Address: 1215 Edward Street, Hearst, Ontario, P0L 1N0
Tel: (705) 362-8481 Fax: (705) 362-4684

PREPARED BY: **R.A. LeCraw, P.Eng.**

DATE: Plant Visit June 18, 1996

STAFF:
Superintendent: André Doucet
No. of Operators: 2

Hours of Operation with Staff: 8 h/d

Names of Operators:
- Stéphane Jolin
- Claude Brochu

Certified Y/N: Class 3

PLANT CAPACITY:
Average Daily Flow: 2,200 m^3/d (0.5 MIGD)
Max. daily Flow: 3,700 m^3/d (0.8 MIGD)
Rated Plant Capacity: 11,180 m^3/d (2.46 MIGD)
Population Served: 5,962 (1991)

OPERATING AUTHORITY: **OCWA**

YEAR OF CONSTRUCTION: **1977**

SOURCE OF RAW WATER: Mattawishkwia River

RAW WATER CHARACTERISTICS:

Colour:	100 - 136 TCU
Turbidity:	2.2 - 7.3 NTU
pH:	7.0 - 7.6
Alkalinity:	36 - 90 mg/L

CHEMICALS:

- Coagulant: Type: Alum
  Dosage: 142 – 193 mg/L
  Injection Point: Raw water main. Just past low lift pumping station.
- Coagulant Aid: Type: None
  Dosage:
  Injection Point:
- Alkalinity/pH Adjustment: Type: Lime for pre-alkalinity adjustment.
  Dosage: 26 – 53 mg/L
  Injection Point: Raw water main.
- Disinfection: Type: Chlorine gas
  Dosage: Pre: 1 mg/L. Post: 0.8 – 2.7 mg/L
  Injection Point: Pre: Raw water. Post: Suction of high lift pump.
- Other: Type: Ammonium sulphate
  Dosage: Pre and Post: 0.4 to 0.8 mg/L
  Injection Point: Pre: Into raw water well. Post: Into pump suction with Cl_2.

ANALYSIS DONE ON-SITE:

LAB EQUIPMENT AVAILABLE:

PROCESS CONFIGURATION:

CHEMICALS METERING:

	TYPE	CAPACITY	CONTROL	CONDITION
Coagulant: Alum	2 positive displacement diaphram metering pumps	1.6 L/min	Presently manual. New SCR Drives ordered to return to flow paced.	Fair
Coagulant Aid: None				
Alkalinity/pH Adjustment: Lime	Volumetric Feed		Manual adjustment. pH monitoring and alum from flocculation tank.	
Disinfection: Cl_2 Gas for Pre and Post Chloramination	3V-Notch chlorinators (2 duty/1 standby)	182 kg/d		
Other: Ammonium Sulphate (Pre and Post)				

PLANT CONTROL:

- Flow (Manual Set/Auto): Raw Water Manual Set.
- Clearwell Level:
- On/Off:

PROCESS MONITORING:

PARAMETERS	INSTRUMENT	MONITORING FREQUENCY	LOCATION	NOTES
• Turbidity:	1720 C	Continuous	Filter effluent	
• pH:	Hach		-Flocculation tanks -Plant Effluent	Need repair
• Total Chlorine Residual:	Hach		Plant Effluent	
• Temperature:	Lab			
• Aluminum Residual:	Hach DR2000 Lab			
• Colour:	Hach DR2000 Lab			
• Other:				

ISSUES:

- The hydraulic loading is well below the rated capacity of the treatment process which is contributing to the good performance of the alum alone. The plant treated turbidities and colour are excellent.

- The plant was previously post-chloraminating after the reservoir prior to the study but once the THMs issue was identified, the OCWA operating staff implemented pre-chloramination as well. As a result, THMs formation is low and well below the new provincial guideline.

- The level of combined chlorine residual being maintained is low and it was recommended to OCWA that the total chlorine residual should be maintained between 1.5 to 2.0 mg/L through the reservoir in order to achieve adequate disinfection. It is also important to prevent nitrification in the distribution system.

CHECK LIST:

_	Copy of Certificate of Approval.	Yes
_	Copy of DWSP report if available.	N/A
_	Copy of monthly flows for the previous year.	Yes
_	Copy of the monthly analysis for the previous year to evaluate plant performance for the raw water, settled water and plant effluent.	Yes
	Analysis of interest are: DOC, true colour, turbidity, pH, alkalinity, aluminum residual, chlorine residual, temperature and THMs.	Yes

Certificate of Approval

Appendix B

Environment

Ontario

Certificate of Approval
(Water)

Whereas ------------------------PROVINCE OF ONTARIO--------------------------

XX

has applied in accordance with Section 41 of The Ontario Water Resources Act for approval of: 18

Construction of water works facilities to serve the Town of Hearst, (Project No. 5-0136, Contract No. 3) as follows:

WATER TREATMENT PLANT

-construction of a 2.46 MIGD Water Treatment Plant to be located south of Edward Street approximately 250 feet west of Twelfth Street in the Town of Hearst, consisting of the following:

LOW LIFT STATION

-modifications to the existing raw water pumping station including the removal of the existing pumping units, (for installation in the new high lift station), and the installation of three submersible low lift pumps, one as standby, each capable of pumping 1.23 MIGD against a total dynamic head of 43 feet; the existing 16 inch diameter intake pipe extending into the Mattawishkwia River and the manually cleaned intake screens to be maintained;

FLOCCULATORS

-two (2) sets of spiral flow flocculation tanks each with three (3) cells approximately 9.5' x 9.5' x 21' deep;

-the flocculation tanks are arranged for parallel flow through the two sets with the maximum flow through each set to be 1.23 MIGD providing a detention time of approximately 37 minutes;

SETTLING TANKS

-two (2) settling tanks, each 20' x 50' x 21' deep, arranged for parallel operation to provide approximately 2.5 hours detention at a maximum flow of 1.23 MIGD through each tank, (overflow rate approximately 1230 GPD/ft^2);

-settling tanks to be equipped with syphoning equipment for removal of sludge to discharge to a sludge holding tank;

FILTERS

-two (2) dual media filters each having a surface area of 256 square feet;

Now therefore this is to certify that after due enquiry the said proposed works have been approved under Section 41 of The Ontario Water Resources Act.

DATED AT TORONTO this 2nd day of December 1977

Ontario

Certificate of Approval
(Water)

Whereas ----------------¿---------------

of

has applied in accordance with Section 41 of The Ontario Water Resources Act for approval of:-

-design filter rate 3.33 Imperial gallons per minute per square foot at 1.23 MIGD through each filter;

-each filter equipped with gravel/sand/anthracite filter media, surface wash system and washwater troughs;

-one (1) washwater pump having a capacity of 5.7 MIGD at 37 feet total dynamic head is to be installed for backwashing the filters, (backwash rate is 15 IGPM per square foot of filter area);

-filtered water discharges to a 90,000 Imperial gallon clear well below the filters;

HIGH LIFT PUMPING STATION

-a high lift pumping station equipped with four (4) horizontal centrifugal pumps with the following capacities:

Unit #1 - 0.5 MIGD at 175 feet T.D.H. (relocated from existing raw water pumping station)

Unit #2 - 1.0 MIGD at 175 feet T.D.H. (relocated from existing raw water pumping station)

Unit #3 - 2.0 MIGD at 175 feet T.D.H. with Diesel Engine drive, (relocated from existing raw water pumping station)

Unit #4 - 1.5 MIGD at 181 feet T.D.H. (new unit)

-high lift pump suctions are taken from an 18 inch diameter suction header connected to the 24 inch diameter pipe between the clear well and the ground storage reservoir;

-the high lift pumps discharge to a 16 inch diameter pump discharge header extending from the station to the 12 inch diameter Trunk Watermain on Edward Street;

-There is a connection from the high lift discharge header to the backwash pump discharge pipe to provide emergency filter backwash;

Now therefore this is to certify that after due enquiry the said proposed works have been approved under Section 41 of The Ontario Water Resources Act.

DATED AT TORONTO this 2nd day of December 1977

Ministry of the
Environment

Ontario

Certificate No. 5-255-77-006

Certificate of Approval
(Water)

Whereas ----------------3----------------

has applied in accordance with Section 41 of The Ontario Water Resources Act for approval of:-

MISCELLANEOUS TANKAGE AND EQUIPMENT

- a chlorine gas system with three (3) V-notch chlorinators, one as standby, to effect prechlorination of the raw water at the low lift pumping station and post-chlorination at the high lift suction header; the chlorinators to be 400#/day capacity, initially equipped with 150#/day rotameters;

-an alum feed system consisting of two (2) 5000 gallon liquid alum storage tanks and two (2) positive displacement diaphragm type chemical feed pumps, one as standby, for feeding liquid alum solution as a coagulant aid to the raw water in the low lift pump discharge; each pump capable of a maximum output of 500 gallons per day;

-a polymer feed system consisting of polymer handling equipment and two (2) positive displacement diaphragm type chemical feed pumps, one as standby, for feeding polymer solution at a maximum rate of 2050 gallons per day to the raw water in the low lift pump discharge, as a coagulant aid;

-a lime feed system for handling and preparing bogged lime into lime slurry for feeding by two (2) positive displacement diaphragm type chemical feed pumps, one as standby, at a maximum rate of 625 gallons per day to the high lift pump suction for PH adjustment of the finished water;

-a 60,000 gallon waste washwater surge tank for storing backwash water for recycling to the low lift pumping station or pumping to the sludge holding tank by the 85 IGPM horizontal centrifugal waste wash water transfer pump;

-a 14,600 gallon sludge holding tank to receive discharge from the clarifier sludge collectors and from the waste washwater surge tank for pumping by a 300 IGPM horizontal centrifugal pump to disposal, (initially to trucks and in the future to the sanitary sewer when capacity is available);

-the installation of a 4.0 KW standby Diesel generator set to provide emergency lighting and instrumentation;

-provision of laboratory facilities in the filter operating gallery;

-provision of office and workshop facilities;

Now therefore this is to certify that after due enquiry the said proposed works have been approved under Section 41 of The Ontario Water Resources Act.

DATED AT TORONTO this 2nd day of December 19 77

Environment

Ontario

Certificate of Approval
(Water)

Whereas ----------------4----------------

XXX

has applied in accordance with Section 41 of The Ontario Water Resources Act for approval of:-

and including all the necessary appurtenances and controls for process and flow monitoring and plant operation;

GROUND STORAGE RESERVOIR

-construction of a 900,000 Imperial gallon ground storage reservoir to be located at the Water Treatment Plant site, reservoir top water level to be at elevation 788; and including a 24 inch diameter pipe interconnecting the reservoir and the Treatment Plant clear well;

TRUNK WATERMAIN

-construction of approximately 1800 feet of 12 inch diameter trunk watermain on Edward Street from the Water Treatment Plant to Ninth Street and including connections to the existing nearest water distribution system at Twelfth Street, Tenth Street and Ninth Street;

and including all the necessary appurtenances and controls, all in accordance with the plans and specifications prepared by Northland Engineering Limited, Consulting Engineers, at a total estimated cost, including engineering and contingencies, of ONE MILLION, NINE HUNDRED AND NINETY FIVE THOUSAND, FIVE HUNDRED AND FORTY DOLLARS ($1,995,540.00).

THIS IS A TRUE COPY OF THE ORIGINAL CERTIFICATE ISSUED

Dec 6/77

(Signed)

Now therefore this is to certify that after due enquiry the said proposed works have been approved under Section 41 of The Ontario Water Resources Act.

DATED AT TORONTO this 2nd day of December 1977.

Attn: Mr. P. Joseph, Project Manager
c.c. Northland Engineering Limited
Mr. C. E. McIntyre, MOE Reg. Dir.
Mr. J. Toth, Design & Equip

Analytical Procedures used by Novamann

Appendix C

Detection Limit and Analytical Method Reference used by Novamann

PARAMETERS	MINIMUM DETECTION LIMIT(MDL)	ANALYTICAL METHOD	METHOD REFERENCE*
THM	6 µg/L	Purge &Trap GC/MS	EPA 624
TOC	0.1 mg/L	UV/PEROX/FID	EPA 9060
residual aluminum	0.025 mg/L	ICP	EPA 6010
turbidity	0.1 NTU	Turbidity Meter	APHA 2130
true colour	1 TCU	Colourimetric	APHA 2120
pH	0.01	pH Meter	APHA 4500H
alkalinity	1 mg/L - $CaCO_3$	Titration	APHA 2320
ammonia + ammonium	0.05 mg/L	Colourimetric	APHA 4500
anions (NO_3, Cl, SO_4, F)	0.1 to 0.5 mg/L	Ion Chromatography	EPA 300.0
conductivity	1 umho	Conductivity Meter	APHA 2510
lead	0.002 mg/L	Graphite Furnace	EPA 7421
metals		ICP	EPA 6010
nitrite	0.1 mg/L	Colourimetric	APHA 4500
orthophosphate-P	0.005 mg/L	Colourimetric	APHA 4500

Note * : EPA : Environmental Protection Agency
APHA : American Public Health Association

Evaluation of Residual Chlorine Concentration for Inactivation of Giardia Cysts

Appendix D

HEARST WATER TREATMENT PLANT

D.1 Evaluation of free chlorine dosage for inactivation of Giardia Cysts for T= 0.5 °C:

NOTES:

- The SWTR establishes CTs for chlorine, chlorine dioxide, ozone and chloramines which will achieve 3-log inactivation of Giardia Cysts.
- Well operated conventional treatment plants which have been optimized for turbidity removal can be expected to achieve at least a 2.5-log removal of Giardia Cysts.

CT for 0.5-log inactivation = 46.5 (at 0.5 °C or lower, pH=7.5 and Conc.= 1.7 mg/L)

Where C = Concentration (mg/L)
T = Contact Time (min)

Evaluation of contact time (T):

T= [Volume of Clearwell (m^3) x %Full x Baffling Condition (T_{10}/T)] / [Maximum Flowrate (m^3/d)] x 1,440 min/d

Volume of Clearwell =	409 m^3	
% Full =	0.5	
T_{10}/T =	0.5	(Clearwell and baffles installed)
Max. Flowrate =	5,500 m^3/d	

T = 27 Minutes

Evaluation of Free Chlorine Concentration (C):

C = CT for 0.5-log inactivation / T

CT = 46.5

$$\boxed{C = 1.74 \text{ mg/L}}$$

HEARST WATER TREATMENT PLANT

D.2 Evaluation of free chlorine dosage for inactivation of Giardia Cysts for T= 5 °C:

NOTES:

- The SWTR establishes CTs for chlorine, chlorine dioxide, ozone and chloramines which will achieve 3-log inactivation of Giardia Cysts.
- Well operated conventional treatment plants which have been optimized for turbidity removal can be expected to achieve at least a 2.5-log removal of Giardia Cysts.

CT for 0.5-log inactivation = 30.5 (at 5 °C or lower, pH=7.5 and Conc.= 1.1 mg/L)

Where C = Concentration (mg/L)
T = Contact Time (min)

Evaluation of contact time (T):

T= [Volume of Clearwell (m^3) x %Full x Baffling Condition (T_{10}/T)] / [Maximum Flowrate (m^3/d)] x 1,440 min/d

Volume of Clearwell = 409 m^3
% Full = 0.5
T_{10}/T = 0.5 (Clearwell and baffles installed)
Max. Flowrate = 5,500 m^3/d

T = 27 Minutes

Evaluation of Free Chlorine Concentration (C):

C = CT for 0.5-log inactivation / T

CT = 30.5

$\boxed{C = \textbf{1.14 mg/L}}$

HEARST WATER TREATMENT PLANT

D.3 Evaluation of free chlorine dosage for inactivation of Giardia Cysts for T= 10 °C:

NOTES:

* The SWTR establishes CTs for chlorine, chlorine dioxide, ozone and chloramines which will achieve 3-log inactivation of Giardia Cysts.

* Well operated conventional treatment plants which have been optimized for turbidity removal can be expected to achieve at least a 2.5-log removal of Giardia Cysts.

CT for 0.5-log inactivation = 22 (at 10 °C or lower, pH=7.5 and Conc.= 0.8 mg/L)

Where C = Concentration (mg/L)
T = Contact Time (min)

Evaluation of contact time (T):

T= [Volume of Clearwell (m^3) x %Full x Baffling Condition (T_{10}/T)] / [Maximum Flowrate (m^3/d)] x 1,440 min/d

Volume of Clearwell = 409 m^3
% Full = 0.5
T_{10}/T = 0.5 (Clearwell and baffles installed)
Max. Flowrate = 5,500 m^3/d

T = 27 Minutes

Evaluation of Free Chlorine Concentration (C):

C = CT for 0.5-log inactivation / T

CT = 22

C = 0.82 mg/L

HEARST WATER TREATMENT PLANT

D.4 Evaluation of free chlorine dosage for inactivation of Giardia Cysts for T= 15 °C:

NOTES:

- The SWTR establishes CTs for chlorine, chlorine dioxide, ozone and chloramines which will achieve 3-log inactivation of Giardia Cysts.
- Well operated conventional treatment plants which have been optimized for turbidity removal can be expected to achieve at least a 2.5-log removal of Giardia Cysts.

CT for 0.5-log inactivation = 14 (at 15 °C or lower, pH=7.5 and Conc.= 0.5 mg/L)

Where C = Concentration (mg/L)
T = Contact Time (min)

Evaluation of contact time (T):

T= [Volume of Clearwell (m^3) x %Full x Baffling Condition (T_{10}/T)] / [Maximum Flowrate (m^3/d)] x 1,440 min/d

Volume of Clearwell = 409 m^3
% Full = 0.5
T_{10}/T = 0.5 (Clearwell and baffles installed)
Max. Flowrate = 5,500 m^3/d

T = 27 Minutes

Evaluation of Free Chlorine Concentration (C):

C = CT for 0.5-log inactivation / T

CT = 14

$\boxed{C = \textbf{0.52 mg/L}}$

HEARST WATER TREATMENT PLANT

D.5 Evaluation of free chlorine dosage for inactivation of Giardia Cysts for T= 20 °C:

NOTES:

- The SWTR establishes CTs for chlorine, chlorine dioxide, ozone and chloramines which will achieve 3-log inactivation of Giardia Cysts.
- Well operated conventional treatment plants which have been optimized for turbidity removal can be expected to achieve at least a 2.5-log removal of Giardia Cysts.

CT for 0.5-log inactivation = 10 (at 20 °C or lower, pH=7.5 and Conc.<= 0.4 mg/L)

Where C = Concentration (mg/L)
T = Contact Time (min)

Evaluation of contact time (T):

T= [Volume of Clearwell (m^3) x %Full x Baffling Condition (T_{10}/T)] / [Maximum Flowrate (m^3/d)] x 1,440 min/d

Volume of Clearwell = 409 m^3
% Full = 0.5
T_{10}/T = 0.5 (Clearwell and baffles installed)
Max. Flowrate = 5,500 m^3/d

T = 27 Minutes

Evaluation of Free Chlorine Concentration (C):

C = CT for 0.5-log inactivation / T

CT = 10

$\boxed{C = 0.37 \text{ mg/L}}$

HEARST WATER TREATMENT PLANT

D.8 Evaluation of free chlorine dosage for inactivation of Giardia Cysts for T= 10 °C, and plant flow rate of 7,252 m^3/d:

NOTES:

- The SWTR establishes CTs for chlorine, chlorine dioxide, ozone and chloramines which will achieve 3-log inactivation of Giardia Cysts.
- Well operated conventional treatment plants which have been optimized for turbidity removal can be expected to achieve at least a 2.5-log removal of Giardia Cysts.

CT for 0.5-log inactivation = 22.5 (at 10 °C or lower, pH=7.5 and Conc. = 1.1 mg/L)

Where C = Concentration (mg/L)
T = Contact Time (min)

Evaluation of contact time (T):

T= [Volume of Clearwell (m^3) x %Full x Baffling Condition (T_{10}/T)] / [Maximum Day Flow (m^3/d)] x 1,440 min/d

Volume of Clearwell = 409 m^3
% Full = 0.5
T_{10}/T = 0.5
Max. Day Flow = 7,252 m^3/d (Spring and fall conditions)

T = **20 Minutes**

Evaluation of Free Chlorine Concentration (C):

C = CT for 0.5-log inactivation / T

CT = 22.5

$\boxed{C = \mathbf{1.11\ mg/L}}$

D.9 Evaluation of free chlorine dosage for inactivation of Giardia Cysts for T= 15 °C, and plant flow rate of 9,065 m^3/d

NOTES:

- The SWTR establishes CTs for chlorine, chlorine dioxide, ozone and chloramines which will achieve 3-log inactivation of Giardia Cysts.
- Well operated conventional treatment plants which have been optimized for turbidity removal can be expected to achieve at least a 2.5-log removal of Giardia Cysts.

CT for 0.5-log inactivation = 15 (at 15 °C or lower, pH=7.5 and Conc. = 1.0 mg/L)

Where C = Concentration (mg/L)
T = Contact Time (min)

Evaluation of contact time (T):

T= [Volume of Clearwell (m^3) x %Full x Baffling Condition (T_{10}/T)] / [Maximum Day Flow (m^3/d)] x 1,440 min/d

Volume of Clearwell = 409 m^3
% Full = 0.5
T_{10}/T = 0.5
Max. Day Flow = 9,065 m^3/d (Summer conditions)

T = **16 Minutes**

Evaluation of Free Chlorine Concentration (C):

C = CT for 0.5-log inactivation / T

CT = 15

$\boxed{C = \mathbf{0.92\ mg/L}}$

HEARST WATER TREATMENT PLANT

D.10 Evaluation of free chlorine dosage for inactivation of Giardia Cysts for T= 20 °C, and plant rated capacity (11,180 m^3/d):

NOTES:

- The SWTR establishes CTs for chlorine, chlorine dioxide, ozone and chloramines which will achieve 3-log inactivation of Giardia Cysts.
- Well operated conventional treatment plants which have been optimized for turbidity removal can be expected to achieve at least a 2.5-log removal of Giardia Cysts.

CT for 0.5-log inactivation = 11 (at 20 °C or lower, pH=7.5 and Conc. = 0.8 mg/L)

Where C = Concentration (mg/L)
T = Contact Time (min)

Evaluation of contact time (T):

T= [Volume of Clearwell (m^3) x %Full x Baffling Condition (T_{10}/T)] / [Maximum Day Flow (m^3/d)] x 1,440 min/d

Volume of Clearwell = 409 m^3
% Full = 0.5
T_{10}/T = 0.5
Max. Day Flow = 11,180 m^3/d (Summer conditions)

T = 13 Minutes

Evaluation of Free Chlorine Concentration (C):

C = CT for 0.5-log inactivation / T

CT = 11

$\boxed{C = 0.84 \text{ mg/L}}$